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NATURAL GAS

FROM

UNCONVENTIONAL

GEOLOGIC SOURCES

BOARD ON MINERAL RESOURCES

COMMISSION ON NATURAL RESOURCES

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C.

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

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ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

SECTION II

GAS FROM BROWN SHALES

CHAPTER 5

DEVONIAN SHALE AS SOURCE OF GAS

John Avila

GENERAL STATEMENT

Eastern Kentucky has produced natural gas commercially from the Devonian Shale since approximately 1921. Up to the present our exploration for gas in the Brown Shale has usually been secondary to the exploration of other formations. If we fail to find a productive horizon in other formations, the Brown Shale is stimulated in the hope of making a productive well.

The reasons the Brown Shale is not considered a primary objective are as follows:

A. Slow rate of return on invested capital--it takes 7 to 12 years to recover the investment in the typical development of a well in shale, based on current gas price to the major gas companies of 52¢ per Mcf.

B. Knowledge of reservoir characteristics is not reliable--such as actual thickness of the productive zone or "pay zone", porosity values, water saturation, and so on.

C. To improve the well completion technique, we need to know where the gas is coming from, type of reservoir entrapment, and best possible way to release the gas from the rock.

D. There is a need for improved exploration tools and wire line logs to provide better geologic, engineering, and well-completion information.

E. Improved well-completion methods will increase gas deliverability.

There is an imperative need for a detailed study of the Devonian Brown Shale and for research to determine the most feasible way of extracting additional quantities of natural gas from the shale. The vast regional extent in which the shale was deposited makes it a very significant source of gas. Shultz (1962) estimated that "the near-surface deposits in Kentucky and Indiana would yield 130 Tcf of methane by an alternative gasification process."

(For the purpose of this paper the names Chattanooga, Ohio, New Albany, and Brown Shale are synonymous.)

GEOLOGY OF UPPER DEVONIAN SHALES OF THE APPALACHIAN BASIN

The structure of the Appalachian Basin can be visualized from a brief review of its history. The highlands to the northeast and east of the Appalachian geosyncline started to rise during Middle Devonian time and culminated in late Devonian. Sediments eroded from the highlands formed thick clastic wedges of nearshore and deltaic sediments. Muds from the Catskill-Chemung delta complex filled the gradually subsiding Appalachian Trough, and the deposition continued westward, onlapping on successively older beds. The late Devonian muds eventually crossed the Cincinnati Arch into the Illinois and Michigan basins. These major transgressing epeiric seas continued until most of the eastern and mid-continent region was under cover of upper Devonian and lower Mississippian sedimentary deposits. (See Figure 5.1.)

Much can be said about the regional depositional environment which existed when the Brown Shale was deposited. It is my opinion that the sediments were deposited in a broad, shallow basin with brackish marine conditions where the waters were stagnant and toxic. The rate of deposition must have been very slow and uniform, and abundant plant matter was available in a warm humid climate. This type of environment was certainly conducive to the generation of gas.

The Late Devonian Shale as a Gas Producer

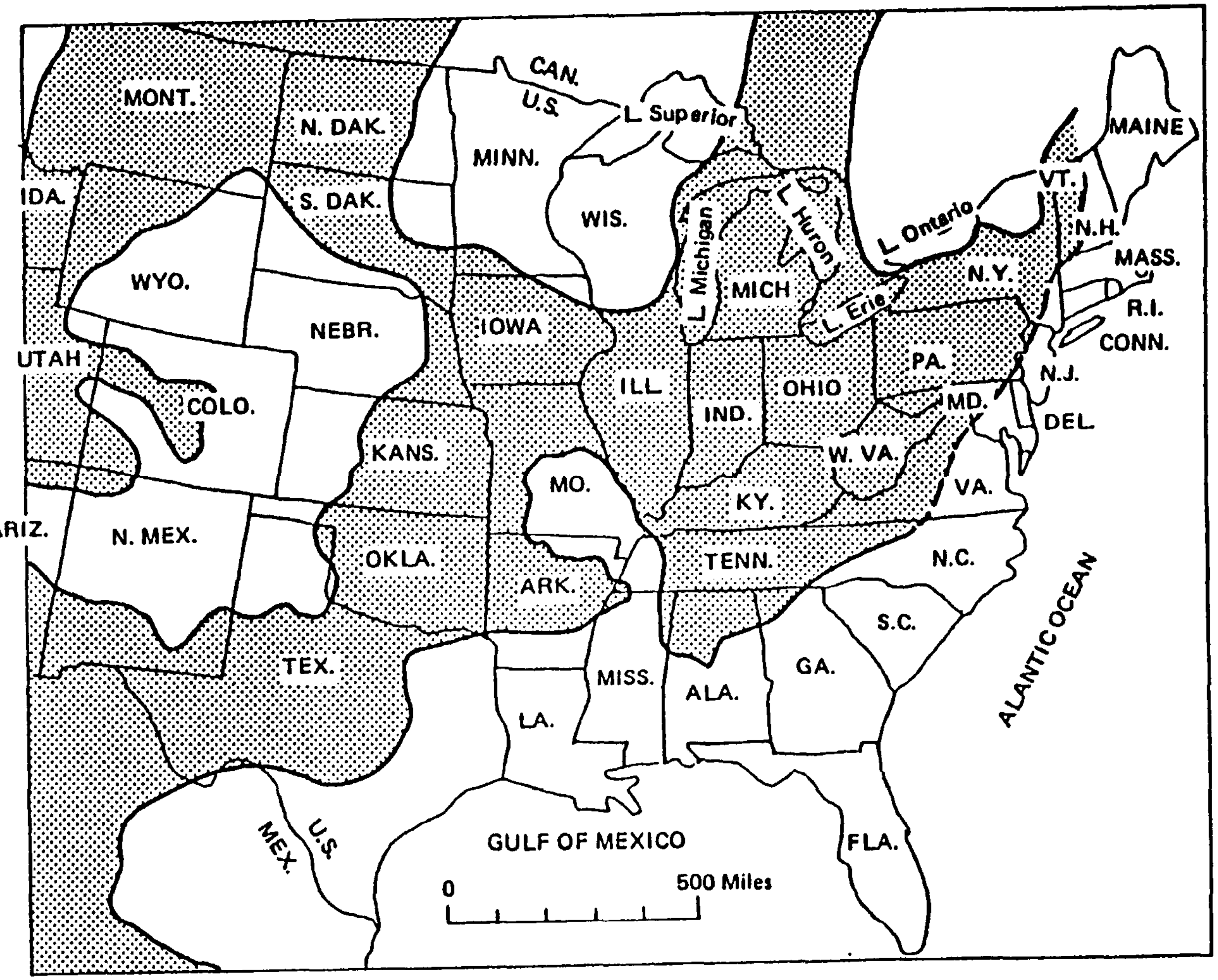
The Brown Shale of Eastern Kentucky accounts for 80 percent of Kentucky's 1974 production of approximately 69.7 Bcf of gas (Carpenter et al. 1975). The total cumulative gas production in Kentucky is estimated to be 3.1 Tcf (Independent Petroleum Association of America 1975:30-31) to the end of December 1974. These figures are impressive, especially since the lack of natural gas could affect employment and the economy of the state and our nation.

Many oil and gas operators feel that the Brown Shale is not worth drilling because of its low profit-to-investment ratio. If the price structure per Mcf were to improve, it would provide an incentive for an operator to explore for shale gas; this would open large areas for the exploration of the shale. The Brown Shale has good potential as a gas producer in areas other than Eastern Kentucky and West Virginia. (See Figure 5.2.)

Grayson and Christian Counties, Kentucky, have reported gas wells or gas shows from the Brown Shale section. Meade County, Kentucky, produced enough gas from the Brown Shale to supply the city of Louisville in the late 1880s; one well was rated at 750,000 cubic feet per day (cf/day). Salt water was associated with this shale gas production (McFarlan 1950).

FIGURE 5.1

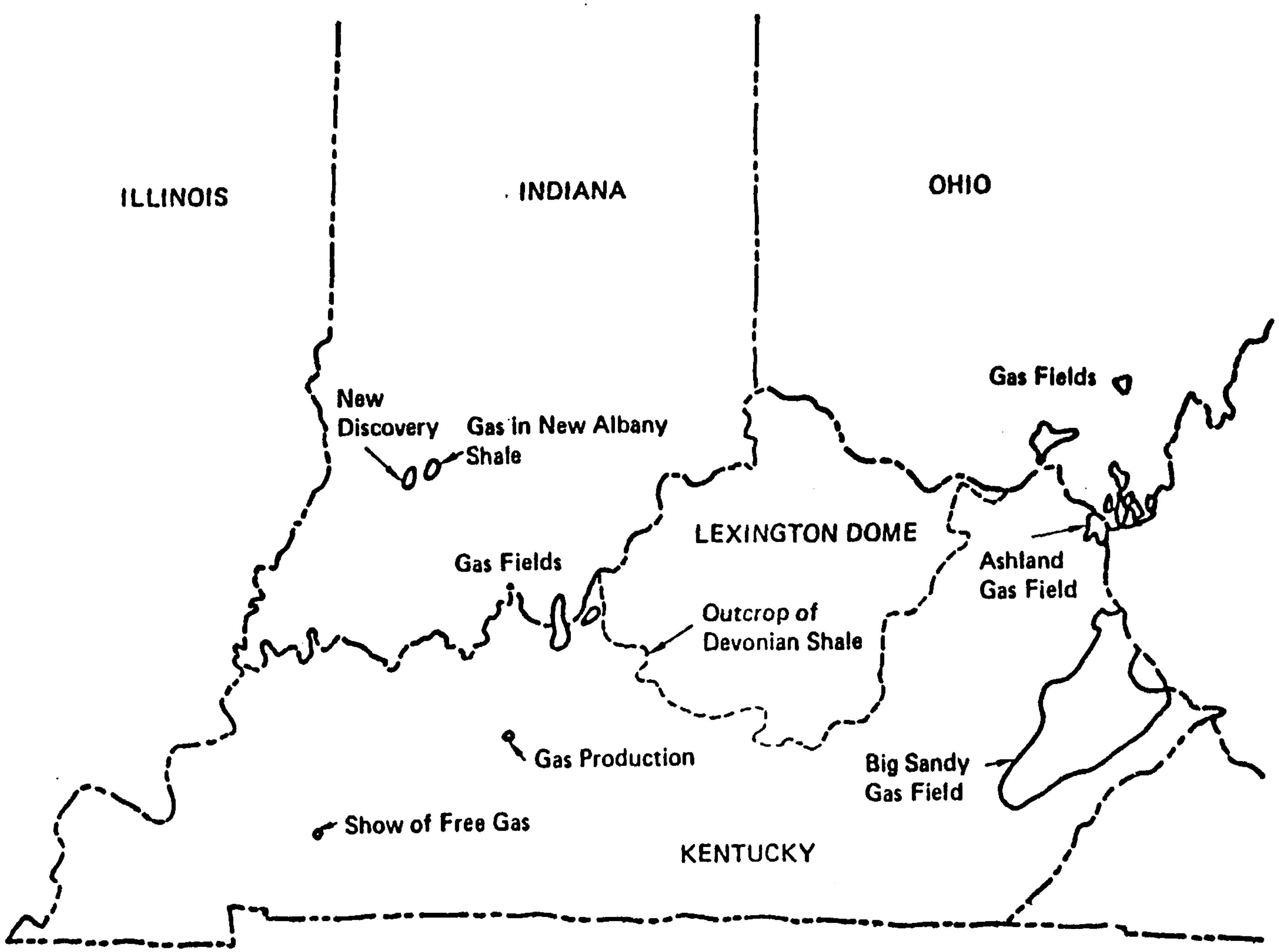
Presumed Original Distribution of Upper Devonian and Lower Mississippian Rocks in Eastern and Central United States



Source: Lineback (1970) and USGS (1961)

FIGURE 5.2

Principal Brown Shale Gas Pools of Eastern United States



In Indiana, gas has been produced from the Brown Shale in the southern part of Harrison County, adjoining Meade County, Kentucky. Estimated open flows from the general area ran as high as 7,500,000 cfpd in the late 1880s. Production of gas came from an upper and lower interval in the shale and from a near-surface depth to 700 feet, with reservoir pressures of 50 to 126 psi. Average life of a commercial gas well in Harrison County was about 20 years or longer. It is estimated that the total production from the area was 5 Bcf. The Loogootee North Gas Field in Martin County, Indiana, has 9 gas wells ranging in depth from 1500 to 1600 feet with initial flows of gas from 200,000 to 2,000,000 cfpd. This "reservoir", is also associated with free salt water. BTU rating of the gas is 980 (Sorgenfrei 1952). The most recent discovery is a well drilled in Davies County, Indiana, with a natural flow of 250,000 cf/day from an interval at 1680 to 1780 feet depth with a final shut-in pressure of 660 psi.

Illinois has not produced gas from the New Albany Shale, but it is believed to be the source beds for the oil found in the Devonian and Silurian formations (Stevenson and Dickerson 1969:4). The oil produced from these systems is in excess of 100 million barrels of oil.

DEVONIAN SHALES OF EASTERN KENTUCKY

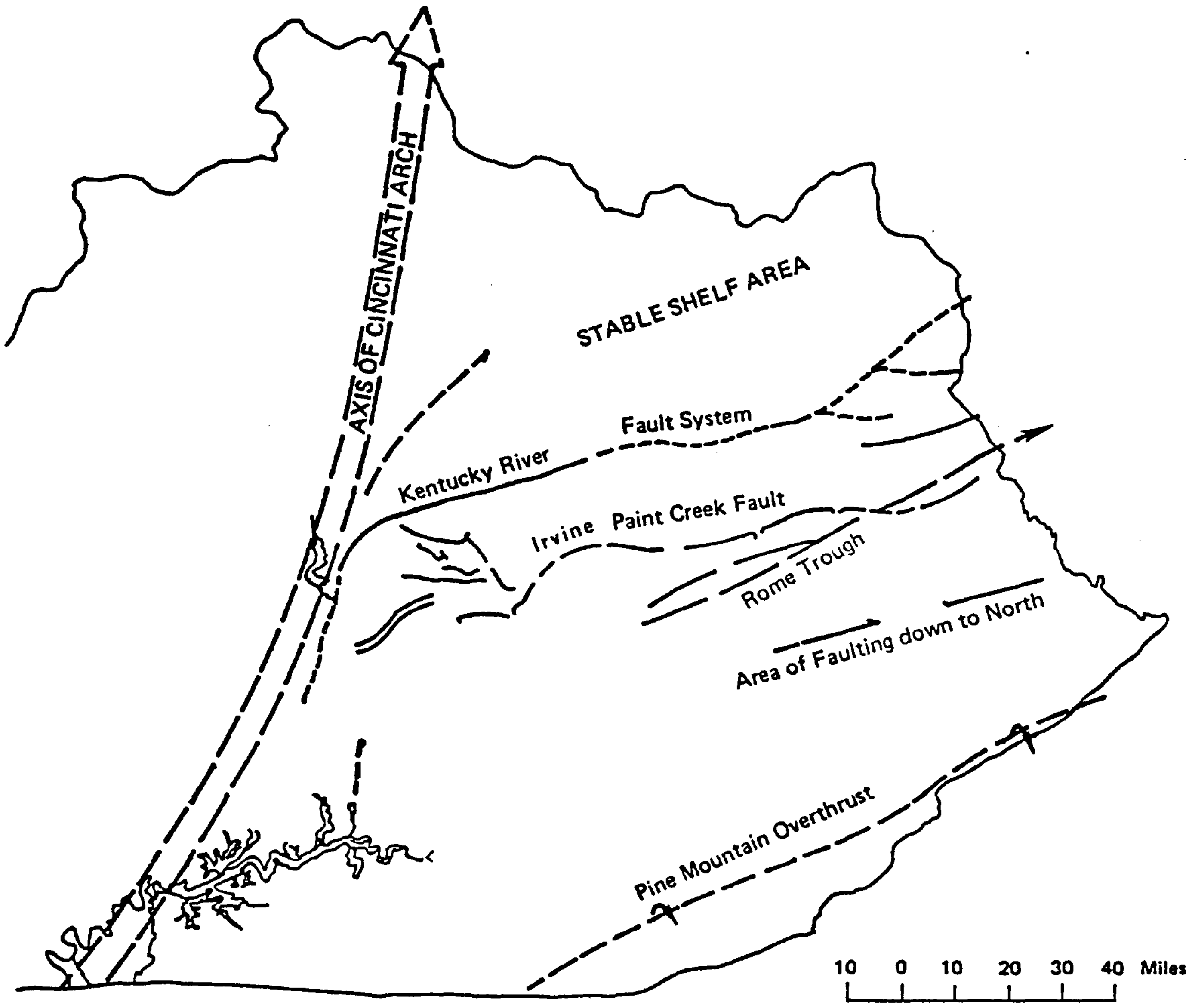
The Brown Shale of Eastern Kentucky lies unconformably on the Corniferous Limestone of Middle Devonian age and is overlain generally by the Berea Siltstone in the east half of Kentucky. It thins westward to the Cincinnati Arch and crops out around the Lexington Dome. South of the Lexington Dome the Brown Shale crosses the Cincinnati Arch, and then thickens into the Illinois Basin.

In Pike County, Kentucky, the Brown Shale reaches its maximum depth of approximately 5000 feet and a thickness of 1000 to 1500 feet. The regional structure of the Brown Shale generally conforms to the present day shallow structural features.

Eastern Kentucky has three major east-west trending surface fault expressions: Kentucky River Fault System, Irving Paint Creek Fault Zone, and Johnson Creek Fault. (See Figure 5.3.) These faults are normal with the downthrow to the south. The system of faulting may make an important contribution to the release of gas from the Brown Shale. With the advent of deeper drilling in recent years, it has been found that the Basement in Eastern Kentucky is highly faulted. These faults generally exhibit growth movement on the downthrow side of the fault. The faults are high-angle normal faults. Some geologists believe wrench faulting has taken place in the major fault zones of the Basement. The vertical displacement varies from several hundred to over 2,700 feet (Avila 1971). The large fault

FIGURE 5.3

Regional Structural Elements of Eastern Kentucky



Geographic base adapted from U.S. Geological Survey 7½ minute topographic maps displacements occurred in Cambrian time, with successively decreasing differential subsidence throughout the remaining Paleozoic period.

The Brown Shale is thinly bedded in outcrops and has a tendency to split into thin layers. Occasional random joints traverse the horizontal laminations. In well cuttings, the shale appears to display numerous hairline bedding planes. These paper-thin laminations occur along very thin layers of rich carbonaceous material. It is the writer's opinion that the gradual Basement sinking may have been responsible for creating permeability in the shale by:

A. Creating openings along bedding planes in a brittle compact shale due to differential Basement settling. Lamination will open or split in areas where there is a difference in texture due to change of grain size or composition of the shale.

B. Slickensides have been noted (Lafferty 1932) "where several large pieces of shale were blown out of a well which came in natural." This may be due to sagging or movement within the shales during or prior to lithification and during gradual subsidence.

The Brown Shale in well cuttings is coffee brown to dark grayish-brown in color. In the lower half of the shale section it is interbedded with a pale green to greenish-gray, soft, pyritic shale, known as the Olentangy member, which generally makes up about 40 percent of the Brown Shale interval. The Brown Shale has varying amounts of black carbonaceous matter occurring as free particles, or as paper-thin layers with scattered carbonaceous particles. The texture of the shale may be coarse to fine with patches of silt. It is hard, brittle and competent, with occasional zones of soft amorphous shale. The shale is fissile and finely micaceous and pyritic.

Production of gas from the Brown Shale is stratigraphically controlled. The larger Corniferous structures in Eastern Kentucky are not associated with gas production, such as the Paint Creek Uplift in Johnson County, although gas may be present in the shale. Some geologists have indicated that the gas production from the Brown Shale is related to sandstone lenses or sandy zones, but clastic units have not been detected in all cases. Another suggestion is that fractures and joints in the shale constitute the permeability channels for the gas. It is difficult to imagine a fractured and jointed zone that covers 8 or 9 counties without having evidence of large scale structural deformation in the area. Fractures are rarely found in well cuttings and cores of the Brown Shale interval, although it is normal to have some fractures and joints in the shale. The presence of bedding plane permeability appears the most plausible as migration paths for gas. Billingsley was the first to recognize the importance of bedding planes as a reservoir (Billingsley and Ziebold 1932).

The production behavior of the Brown Shale is related to two types of porosities; each one plays an important part in a complicated reservoir and production behavior.

The primary porosity is the void space that may or may not be interconnected, but occurs as apparent and effective porosity. Porosity of the shale ranges from 6 percent to 12 percent throughout the entire Brown Shale interval. The source of gas is probably from the entire shale section (see Figure 5.4). Fresh well cuttings from the Brown Shale show various amounts of gas throughout the shale section. Primary porosity appears to improve over the "hot radioactivity or the rich kerogen zones." The shale porosity may or may not contribute gas to the natural open flow of the well. It is the opinion of the writer that the primary pore space is responsible for the longevity of Brown Shale production. The ultimate gas recovery from the shale should be related to the effectiveness with which the flow from the primary porosity is artificially stimulated.

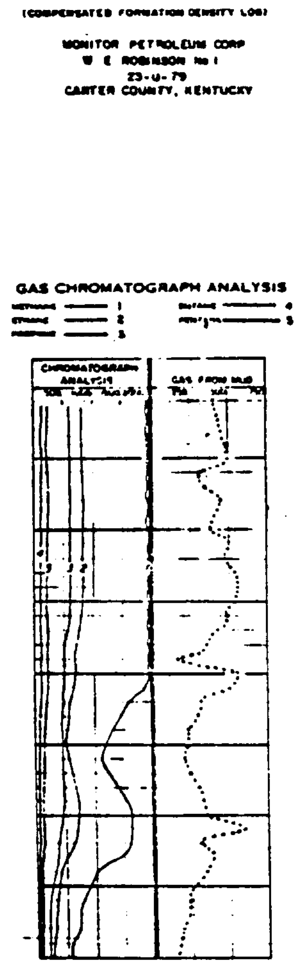
The secondary porosity is effective porosity and is considered here to be fractures, joints, and bedding planes.

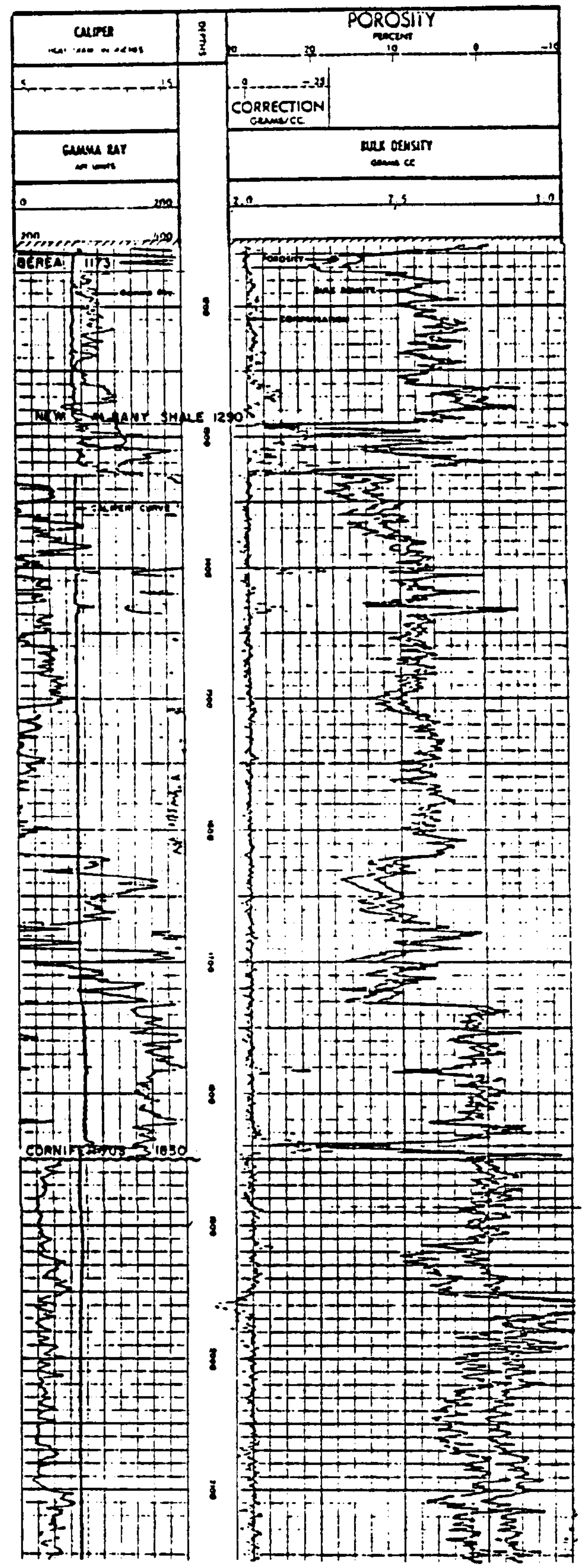
In relating production and reservoir characteristics, Browning (1932) notes that the initial flow of a well declines at a very rapid rate, but the working pressure does not drop in the same proportion; and once the reservoir is shut-in, the working pressure recovers to almost the initial reservoir pressure in a relatively short time. This indicates that once the secondary porosity is drained, there is enough effective primary porosity and permeability to continue to supply gas to the secondary porosity. Gas migrating from the zones of much tighter and lower porosity and moving through kerogen rich beds may explain the statement by Ray (1971:1265-1266) that "older and densely drilled areas of Floyd and Knott Counties are indicating that the BTU values may be increasing with depletion." Enriched gases given off by decaying kerogen beds and mixing with the normal gas could also be the source of higher BTU values with release of gas-pressure from the reservoir.

The Brown Shale entraps two types of gas. The first, as discussed previously, is locked in isolated voids, but can be produced by artificial well stimulation. The second is the gas absorbed in the shale matrix. This gas cannot be produced under normal oilfield conditions. Before this gas can be released, an in-situ combustion or other thermal distillation must be used, and this gas cannot be produced economically at present. Therefore, when estimating gas reserves recoverable from the Brown Shale, the type of gas, the methods of recovery, and the economic conditions should be specified. It may be unrealistic to estimate recovery or production of the second type of gas in the short to intermediate future.

FIGURE 5.4

Generalized Log of Typical Brown Shale Section with Gas Chromatograph Analysis





Source:
Monitor Petroleum Corporation

TABLE 5.1

Brown Shale Total Gas in Place--Eastern Kentucky

Porosity = 10% Water Saturation = 35%	Porosity = 30% Water Saturation = 65%
1.57×10^{14} cf	2.91×10^{14} cf
22.8 cu ft/ton	42.12 cu ft/ton

In Table 5.1 we assumed certain parameters to determine the total gas in place based on total void space only. The area of Brown Shale in Eastern Kentucky was measured by planimeter to the outcrop. Assuming a net average thickness of the Brown Shale to be 228 feet, the volumetric assumptions are:

Reservoir pressure of	400 psi
Reservoir temperature of	90°F
Porosity	10%
Water saturation of	35%
Formation volume factor of	27.94 cf/cu ft

Based on these data the total gas in place for the Brown Shale in Eastern Kentucky is 1.57 Tcf or 22.8 cu ft per ton.

TABLE 5.2

Brown Shale Recovery of Original Gas in Place (OGIP)

Janssens Report

$$\frac{1.01 \text{ cu ft/ton}}{22.8 \text{ cu ft/ton}} = 4.47\% \text{ OGIP}$$

Columbia Report

$$\frac{0.619 \text{ cu ft/ton}}{22.8 \text{ cu ft/ton}} = 2.7\% \text{ OGIP}$$

Since 22.8 cu ft/ton of gas in place was not related to actual production, we decided to relate to Janssens figure of 1.01 cu ft of gas per ton of Brown Shale that will ultimately be produced from the Big Sandy Gas Field of Eastern Kentucky (Janssens 1975). By applying the 22.8 cu ft/ton of gas in place which is based on volumetric calculations, we see that Janssens 1.01 cu ft/ton ultimate recovery amounts to 4.4 percent of original gas in place.

Correspondingly, Columbia Gas reserve assignment for the Brown Shale in their area of interest amounts to 0.619 cu ft/ton and yields 2.7 percent of the original gas in place (Foster 1975).

TABLE 5.3

Typical Brown Shale Well

Average thickness = 400 feet
Average well spacing = 150 acres
Volumetric reserves = 4.75 Bcf
Typical Recovery = 400 MMcf

$$\frac{400\ \text{MMcf}}{4.75\ \text{Bcf}} = 8.4\%\ \text{OGIP}$$

To strengthen this range of recovery factors, we took a typical Brown Shale well with the indicated parameters and an average recovery of 400 MMcf. Volumetric calculation yields 4.75 Bcf with a resulting recovery factor of 8.4 percent of original gas in place.

From the data in Table 5.2 and 5.3, we arrived at a rough estimate of the amount of gas that will be recovered by conventional techniques. It appears that recoverable gas is in the range of 2 to 10 percent of the original gas in place. Therefore, 90 to 98 percent of the gas is left in the ground. It is important to us to improve the conventional techniques for immediate gas results.

Acknowledgments

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